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This document describes the development of cost estimating relationships (CERs) and other cost factors for bombers, tankers, air-to-surface missiles, ICBMs, SSBNs and SLBMs. Both RDT&E and initial procurement cost CERs are presented as are cost factors for support, procurement, recurring procurement, military construction, O&M and military personnel. The (continued)

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Herschel Kanter
Bettina Garcia

August 1985

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PREFACE

For over a decade the Institute for Defense Analyses (IDA) has been engaged in comparing force levels and various aspects of U.S. and USSR military acquisition (RDT&E and procurement) programs for the Office of the Under Secretary of Defense, Research and Engineering. This paper was prepared for that office under Contract MDA 903 84 C 0031, Task Order T-3-150, dated 1 October 1983. This study was under the technical cognizance of Dr. Paul J. Berenson, Special Assistant for Assessment.

This report is based on work originally done by a number of IDA analysts. In particular, the missile and bomber costing is derived from work done by Norman J. Asher, John A. Davis and James H. Henry. The section on tanker costing is extracted from Cost Estimating Relationships for Air and Sealift Mobility Forces, M-54, Institute for Defense Analyses, by Norman J. Asher and William J.E. Shafer. Finally, the SSBN estimate was taken from Cost Estimating Relationships for U.S. Navy Ships, P-1732, Institute for Defense Analyses, by William J.E. Shafer. The more general methodological material was done originally by John A. Davis. Changes were made in all this material to conform to the calculating technique now being used by IDA for Cost and Forces Comparison of U.S. and USSR Strategic Forces, P-1744, Institute for Defense Analyses, by Herschel Kanter and Bettina Garcia.

The methodology is one that is meant to give adequate aggregate cost comparisons. Individual estimates of particular weapons are unlikely to be as reliable as those that might be obtained using a more detailed approach.

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COST METHODOLOGY FOR AGGREGATE U.S. AND USSR STRATEGIC OFFENSIVE FORCE COMPARISONS

A. BACKGROUND AND COST CATEGORIES

The cost methodology presented in this paper was developed from U.S. data solely for the purpose of estimating what it would cost to develop, produce and operate Soviet strategic offensive aircraft, ships and missiles in the United States, and then to compare that estimate of USSR costs with an estimate of the cost of developing, producing and operating U.S. forces--an estimate to be made using the same methodology including cost-estimating relationships (CERs) and cost factors. The estimates are useful only for aggregate comparisons. Use of CERs and cost factors for more detailed estimates of particular weapons systems may be misleading.

The U.S.-USSR cost comparisons were made in terms of outlays. Outlays were derived by first estimating costs in terms of "delivery" dollars (i.e., cost of an aircraft at time of delivery, construction of a base at a time of occupancy, replenishment spares at time of consumption, etc.). The delivery dollars were then converted back to TOA using estimated times from TOA year to delivery year and then lagged to outlays to represent an expenditure or outlay pattern. All three types of costs--delivery, TOA and outlays--have the same cost structure, the only difference being the points in time when the costs are expressed relative to the delivery or completed production of the weapon system.

The outlays are divided into two major cost categories: Investment made up of the research, development, test and evaluation (RDT&E), procurement and military construction appropriation categories, and Operations and Support, made up of two appropriation categories--operations and maintenance (O&M) and military personnel (see Table 1).

Table 1. LISTING OF COST CATEGORIES, APPROPRIATIONS, AND COST ELEMENTS INCLUDING THE COST ESTIMATING RELATIONSHIPS

COST CATEGORY APPROPRIATION COST ELEMENT	Computation of Cost Element
INVESTMENT	- Cost category
RDT&E	- Appropriation
RDT&E	- (A total RDT&E cost for the system at the IOC of the first force unit) for a computed RDT&E cost from the inputted equipment characteristics values (which varies by type equipment and is presented elsewhere).
Procurement - Unit Equipment	- Appropriation
	- (The inputted first unit cost, the inputted slope of the cost-quality curve and the inputted delivery schedule are used to estimate the cost of the cumulative quantity of equipment through year N - the cost of equipment through year N-1) <u>or</u> (the computed first unit cost from the inputted equipment characteristic values (which varies by type equipment and is presented elsewhere) and then continuation as in second step).
Procurement - Support	- (The cost of the unit equipment procurement in year N) x (a support procurement percentage factor).
Procurement - Recurring	- (The average force units in year N) x (a recurring procurement cost per force unit per year).
Military Construction	- Appropriation
Military Construction	- (A total military construction cost for the system at the IOC of the first force unit) <u>or</u> (the incremental construction cost per incremental force unit).
OPERATIONS & SUPPORT	- Cost category
Operations & Maintenance	- Appropriation
Operations & Maintenance	- (The average force units in year N) x (an operations and maintenance cost per force unit per year).
Military Personnel	- Appropriation
Military Personnel	- (The average force units in year N) x (a military personnel cost per force unit per year).
TOTAL COSTS[a]	- Total of Investment and Operations and Support

[a] See discussion earlier in this paper as to delivery dollars, TOA and outlays.

The cost categories and budget appropriations are further divided into cost elements that are the basis for the computation of the cost estimates. Complete descriptions of the cost-estimating relationships and cost factors used for the computation are presented in the following sections.

The estimated costs for each weapon system are aggregated as program outlays. TOA is converted to outlays using the standard OASD (Comptroller) conversion factors. This procedure is discussed in Section B. Program outlays are the costs by year that would be expended during a specific year. The reason for converting to outlays was to derive a number that would be as comparable as possible to CIA dollar cost estimates for the USSR.

Section C presents the CERs used for RDT&E costs and initial procurement costs for all strategic offensive weapon systems. Finally, Section D explains the development of cost factors for military construction, procurement (support and recurring cost elements), operations and maintenance, and military personnel appropriations.

B. CONVERSION TO OUTLAYS

The initial cost estimates are calculated for each weapon system in terms of delivery dollars, that is, dollars assigned to the year the item is delivered or the year when the activity occurs. To properly reflect the estimates as outlays, those costs must be converted to a constructive TOA, that is, to the year the funds must be authorized and appropriated. To accomplish this conversion, lead time factors by appropriation category are applied to all years to convert delivery costs to TOA.

TOA-to-outlay lag factors by appropriation category are then applied to the TOA to reflect that time between the original funding of a weapon system and the time when the funds are expended. Figure 1 is an illustration of the relationship between

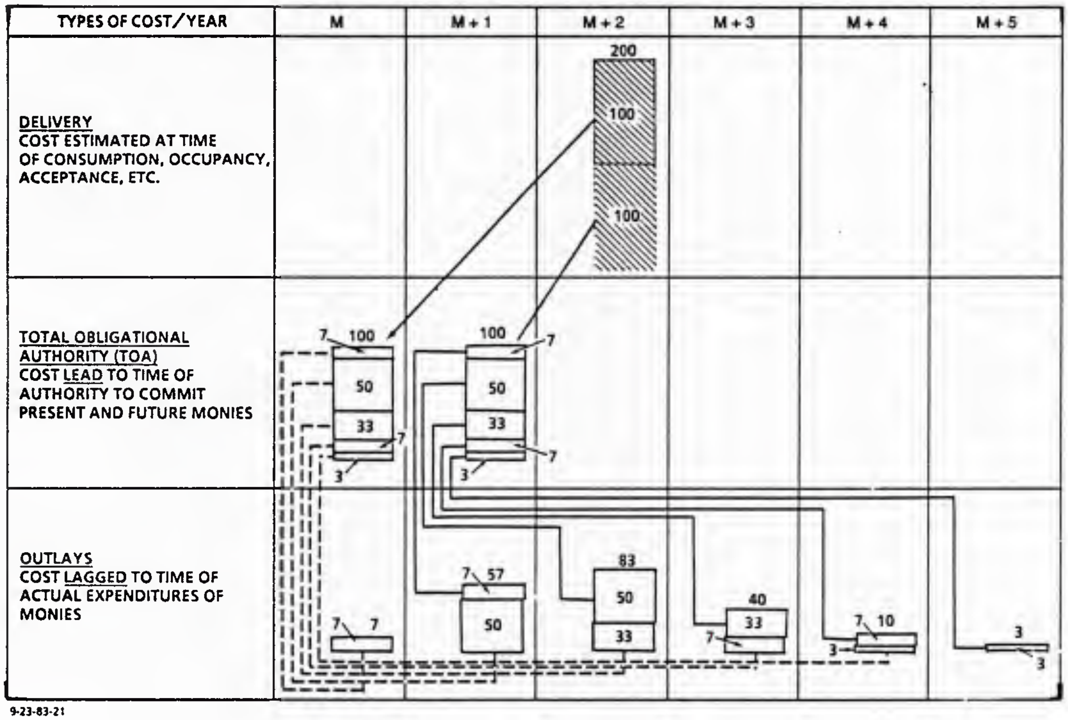

Figure 1. AN ILLUSTRATION OF THE TYPES OF COSTS (AIRCRAFT PROCUREMENT, AIR FORCE)

delivery cost, TOA and outlays for one appropriation category, Aircraft Procurement Air Force (APAF).

Thus the methodology involves spreading the costs by going from deliveries to dollars in the year of delivery to a constructed TOA to outlays. The first step is taken by assuming that TOA funding takes place 6 years before delivery and that TOA funding of aircraft and missiles takes place 1-1/2 years before delivery or, in other words, that TOA funding of one half of the aircraft and missiles takes place 2 years before and the other half 1 year before delivery. The relationship between year of delivery--which is the original date used in the calculation--and TOA year, that is, the year when the weapon is authorized and funds are appropriated is shown as follows:

Weapon Type	TOA Year	Delivery Year
Ships	M	M+6
Aircraft and Missiles	1/2 in M 1/2 in M+1	M+2

For the USSR this is a pure construct used only for the purpose of estimating outlays. For the United States it is an estimate of when TOA would have to occur--on the average. Thus, $2.00 of delivery in 1984 for Air Force aircraft results in $1.00 of TOA in 1983 and $1.00 of TOA in 1982 as shown in Figure 1.

Each of these $1.00s is translated to outlays using the estimated TOA-to-outlay rates used by the Comptroller for each appropriation category and then applied to $1.00 of TOA in year M as shown in Table 2. For example, $1.00 of TOA for Air Force Aircraft results in $0.07 of outlays in year M; $0.50 in year M+1; $0.33 in year M+2, etc. The calculation for combining these two steps is shown in Table 3, that is, splitting a delivery dollar in year M into TOA, half in year M and half in year M+1 and converting this TOA to outlays, using the rates in Table 2.

Table 2. TOA-TO-OUTLAY RATES FOR SELECTED PROCUREMENT APPROPRIATION CATEGORIES

Appropriation Category	Year						
	M	M+1	M+2	M+3	M+4	M+5	M+6
Shipbuilding (SCN)	0.05	0.14	0.19	0.18	0.18	0.18	0.12
Navy Missiles (WPN)	0.14	0.37	0.36	0.08	0.05	0.00	0.00
Air Force Aircraft (APAF)	0.07	0.50	0.33	0.07	0.03	0.00	0.00
Air Force Missiles (MPAF)	0.23	0.37	0.26	0.10	0.04	0.00	0.00

Table 3. DERIVATION OF DELIVERY DOLLAR/OUTLAY RELATIONSHIP

Appropriation Category	Year						
	M	M+1	M+2	M+3	M+4	M+5	M+6
Shipbuilding (SCN)	0.05	0.14	0.19	0.18	0.18	0.18	$\boxed{0.12}$
Navy Missiles (WPN)	0.14	0.37	0.36	0.08	0.05	-	-
	-	0.14	0.37	0.36	0.08	0.05	-
2 Year Total	0.14	0.51	0.73	0.44	0.13	0.05	-
1 Year Average	0.07	0.255	$\boxed{0.365}$	0.22	0.065	0.025	-
Air Force Aircraft (APAF)	0.07	0.50	0.33	0.07	0.03	-	-
	-	0.07	0.50	0.33	0.07	0.03	-
2 Year Total	0.07	0.57	0.83	0.40	0.10	0.03	
1 Year Average	0.35	0.285	$\boxed{0.415}$	0.20	0.05	0.015	-
Air Force Missiles (MPAF)	0.23	0.37	0.26	0.10	0.04	-	-
	-	0.23	0.37	0.26	0.10	0.04	-
2 Year Total	0.23	0.60	0.63	0.36	0.14	0.04	-
1 Year Average	0.115	0.30	$\boxed{0.315}$	0.18	0.07	0.02	-

Note: $\boxed{\quad\quad}$ indicates year of delivery.

This $1.00 for a delivery for Navy missiles in year M+2 translates into $0.07 of outlays in year M, $0.265 in year M+1 and $0.365 in year M+2, the year of delivery (Table 4).

Table 4. DELIVERY DOLLAR TO OUTLAY RATES

	D-6	D-5	D-4	D-3	D-2	D-1	D	D+1	D+2	D+3
SCN	0.050	0.140	0.190	0.180	0.180	0.180	0.120	-	-	-
WPN	-	-	-	-	0.070	0.265	0.365	0.200	0.005	0.025
APAF	-	-	-	-	0.035	0.285	0.415	0.200	0.050	0.015
MPAF	-	-	-	-	0.115	0.300	0.315	0.180	0.070	0.020

C. PROCUREMENT AND RDT&E COST ESTIMATING RELATIONSHIPS

This section describes the development of the CERs for the RDT&E costs and the major equipment costs for the bombers (Section C-1), tanker aircraft (Section C-2), air-to-surface missiles (Section C-3), ICBMs and SLBMs (Section C-4) and SSBN submarines (Section C-5). The section ends with a discussion of the handling of RDT&E costs for partial programs. In Section D the development of cost factors is presented for the military construction, procurement (support and recurring cost elements), operations and maintenance, and military personnel categories.

The purpose for the derivation of these CERs is to estimate the costs of the USSR weapon systems and the U.S. weapon systems in the same consistent manner in order to make aggregate comparisons. Therefore, a basic premise in the development of these CERs must be that they contain only those input values and/or parameters that could be estimated based on observable characteristics of USSR systems. Since use of the outputs of these analyses was limited to the development of long term trends over time between the two countries, the degree of sophistication in the development of these CERs was felt to be satisfactory. Still, the existence of certain shortcomings suggests that slightly more sophisticated CERs may be desirable, even for these aggregate comparisons.

1. Bomber Aircraft

Aircraft characteristics and flyaway[1] lot costs and quantities were collected for seven historical and one pre-production

[1]Flyaway costs is used as a generic term related to the creation of a usable end item of hardware. It includes the basic structure/airframe, propulsion, electronics, and government furnished equipment.

bomber aircraft. The flyaway lot costs and quantities were normalized and a cost/quantity curve was developed for each aircraft. Table 5 presents the first unit cost from the cost/quantity curve and selected aircraft characteristics for each aircraft.

The first unit costs were then regressed against various (additive and multiplicative) combinations of the aircraft characteristics, such as thrust, DCPR[2] weight, take-off gross weight, speed, and time (IOC date). The CER selected for the bomber aircraft is a function of DCPR weight, thrust-to-weight ratio, and time:

$$C = 2.28 \times 10^{-4} W^{0.990} R^{1.643} (1.041)^{IOC-1900}$$

where C = the cost of the first unit in millions of FY 1986 dollars

W = DCPR weight in pounds

R = maximum thrust in pounds

IOC = year of initial operational capability.

Figure 2 illustrates the degree of fit between the estimated and the observed first unit cost of the seven bomber aircraft on a linear scale. This CER was used to estimate the flyaway costs of both the U.S. and USSR bomber aircraft so as to maintain the consistency in the relative comparisons of the bomber aircraft of both countries.

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[2]DCPR weight is the Defense Contractor Planning Report weight.

Table 5. DATA FOR DERIVATION OF FLYAWAY COST CER FOR BOMBER AIRCRAFT

Aircraft	Flyaway Cost First Unit (Millions of FY 86 Dollars)	DCPR Weight (lbs)	Maximum Thrust (lbs)	Maximum Thrust ÷ DCPR Weight	Maximum Take Off Gross Weight (lbs)	Maximum Thrust ÷ Maximum Take Off Gross Weight	IOC[a]
B-47	47	52,260	43,200	0.827	200,000	0.216	1950
B-52	179	112,970	96,800	0.857	450,000	0.215	1954
B-58	238	32,970	62,400	1.893	163,000	0.383	1960
B-57	21	17,740	14,440	0.814	58,000	0.246	1955
A-3/B-66	42	28,170	20,700	0.735	77,300	0.268	1956
FB-111A	139	34,405	40,700	1.183	114,300	0.356	1970
B-1B	695	145,405	120,000	0.825	477,000	0.215	1986

[a] Initial Operational Capability Year.

$$C = 2.28 \times 10^{-4} W^{0.990} R^{1.643} (1.04)^{IOC-1900}$$

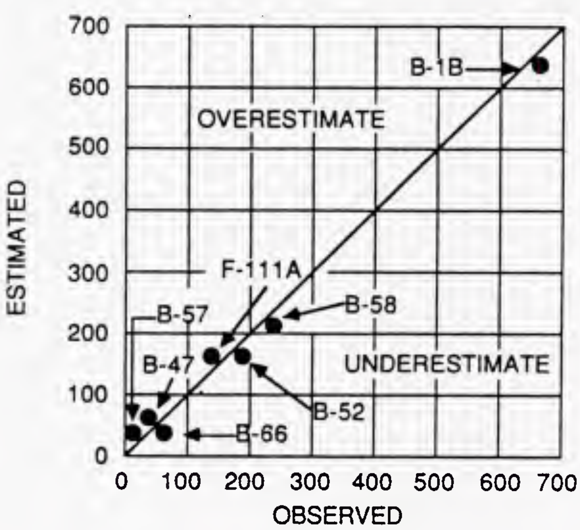

Figure 2. ESTIMATED VERSUS OBSERVED FIRST UNIT FLYAWAY COST U.S. BOMBER AIRCRAFT (In Millions of FY 1986 Dollars)

The data for the bomber aircraft RDT&E was limited to a few observations some of which were follow-on or partial programs; for example, the B-1B followed the B-1, the FB-111 came from a tactical fighter program, the B-70 was cancelled, etc. An aggregate RDT&E CER was developed by associating the DCPR weight and the IOC date to the RDT&E costs for the four aircraft presented in Table 6. The CER is:

$$C = 6.97W^{.37}(1.036)^{IOC-1900}$$

where C = the total RDT&E cost in millions of FY 1986 dollars

W = DCPR weight in pounds

IOC = year of initial operational capability.

Table 6. DATA FOR DERIVATION OF RDT&E CER FOR BOMBER AIRCRAFT

Operational Aircraft	RDT&E (Millions of 86 Dollars)	DCPR Weight (Pounds)	Initial Operational Capability (IOC)
B-52	3,876	112,970	1954
B-58	2,481	32,970	1960
FB-111A	4,706	34,405	1970
B-1B	11,708	145,405	1986

[a]Assumes RDT&E cost of FB-111A as a completely new aircraft would have been equal to the cumulative RDT&E costs of the F-111A/C/D/E/F series.

[b]Cumulative RDT&E cost of B-1A plus B-1B programs.

Figure 3 portrays the relationship between the estimated and the observed RDT&E costs of the four bomber aircraft. Only the B-52 and B-58 were actually completely new aircraft. RDT&E costs of the other two were adjusted in an attempt to approximate their costs as if they had been completely new aircraft for the development of the CER. The B-1B was a continuation and modification of the original B-1 or B-1A program

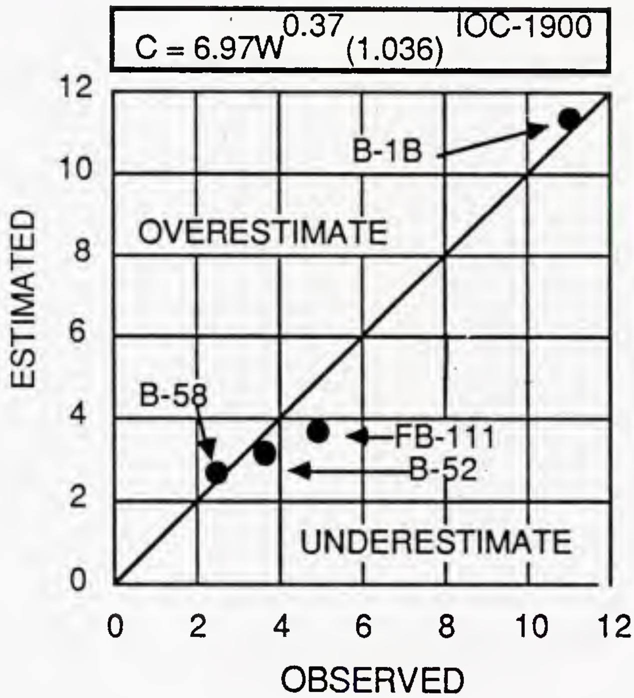

Figure 3. ESTIMATED VERSUS OBSERVED RDT&E COST OF U.S. BOMBER AIRCRAFT (In Billions of FY 1986 Dollars)

which was cancelled, and it was assumed that the development cost of the B-1B as a completely new aircraft would have been equal to the cumulative RDT&E cost of the B-1A plus B-1B programs. The FB-111 although not included in the U.S.-USSR comparison was included in the data set. That aircraft was assumed to be a completely new aircraft whose cost would have been equal to the cumulative RDT&E costs of the F-111A/C/D/E/F series of aircraft.

2. Tankers

Flyaway and RDT&E CERs used for tanker aircraft were taken from Norman J. Asher and William J.E. Shafer, Cost Estimating Relationships for Air and Sealift Mobility Forces, IDA Memorandum Report M-54, March 1983. In this report, aircraft characteristics and flyaway and RDT&E costs were collected for nine historical U.S. military cargo and tanker aircraft programs. Cost data from several sources were collected and normalized for quantities

of aircraft and to constant year dollars. A "best estimate" cumulative average cost for 100 aircraft was developed for each aircraft. Finally, the theoretical first unit flyaway cost was derived based on an assumed 85 percent cumulative average learning curve. The results are presented in Table 7. As can be seen, the piston-powered aircraft were all placed in service during the 1949-1955 period, while the turbine-powered aircraft entered service between 1957 and 1970. Turbine-powered aircraft had considerably higher costs than piston-powered aircraft of similar weight, as would be expected since turbine-powered aircraft represent a higher level of technology and fly at approximately twice the speed of the piston-powered generation of aircraft. Accordingly, it was decided to develop two sets of CERs--one for piston-powered and one for turbine-powered aircraft.

It was not reasonable to include the initial operational capability year in the piston-powered aircraft CERs since those aircraft were all introduced within a 6-year period.

Table 7. DATA FOR DERIVATION OF TRANSPORT AIRCRAFT COST ESTIMATING RELATIONSHIPS

Aircraft	Empty Weight (Thous. Lb)	IOC Year	Theoretical First Unit Flyaway Cost (Million 86 $)	RDT&E Cost (Million 86 $)
Piston-Powered				
C-119	40	1949	13.0	85
C-123	31	1955	11.7	76
C-124	101	1950	33.5	217
C/KC-97	88	1949	32.6	212
Turbine-Powered				
C-130	59	1957	41.1	346
C-141A	134	1965	124.2	668
C-5A	321	1970	409.7	3,246
C-133	117	1958	101.2	539
C/KC-135	98	1957	99.3	527

Consequently there was not sufficient data to calculate the impact of time or of a time-related variable. The IOC year was included in some of the CERs for turbine-powered aircraft CERs, but the relationships were not consistent. Accordingly, the CERs selected use only empty weight as the explanatory variable.

The flyaway CERs are:

Piston-Powered:

$$FC = 0.389(WT)^{0.975}$$

Turbine-Powered:

$$FC = 0.1925(WT)^{1.328}$$

where

FC = First unit flyaway cost in millions of FY 1986 dollars

WT = Empty weight in thousands of pounds.

The first unit flyaway cost estimates based on these equations agree quite well with the observed values (see Figures 4 and 5). Figure 6 shows the relationship of the estimated to observed first unit flyaway costs for both piston-powered and turbine-powered cargo aircraft.

The historical RDT&E costs are less reliable than the flyaway costs because most of the aircraft were developed prior to the time when systematic collection of the data in a more or less uniform way began in 1961 with the institution of the Five Year Defense Program. At the same time, a more uniform method of budgeting was instituted that separated RDT&E and procurement activities into appropriation categories in a more consistent manner. RDT&E costs were obtained for the turbine-powered aircraft, but reliable data for the piston-powered aircraft could

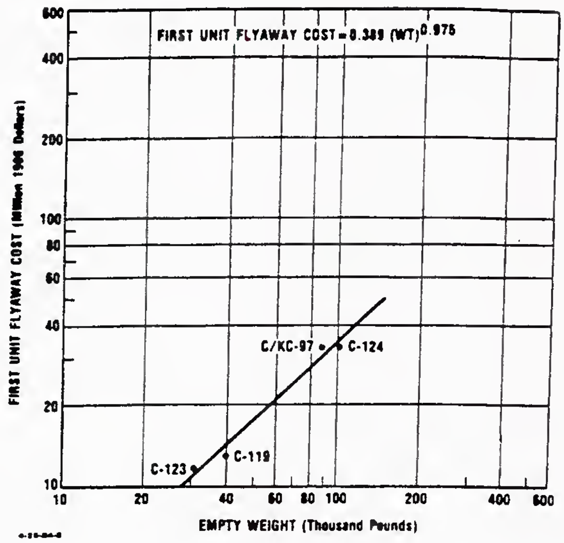

Figure 4. PISTON-POWERED CARGO AIRCRAFT FIRST UNIT FLYAWAY COST (In Millions of FY 1986 Dollars)

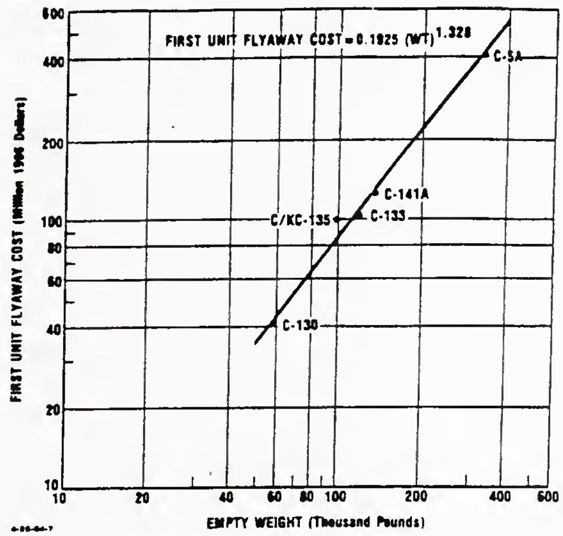

Figure 5. TURBINE-POWERED CARGO AIRCRAFT FIRST UNIT FLYAWAY COST (In Millions of FY 1986 Dollars)

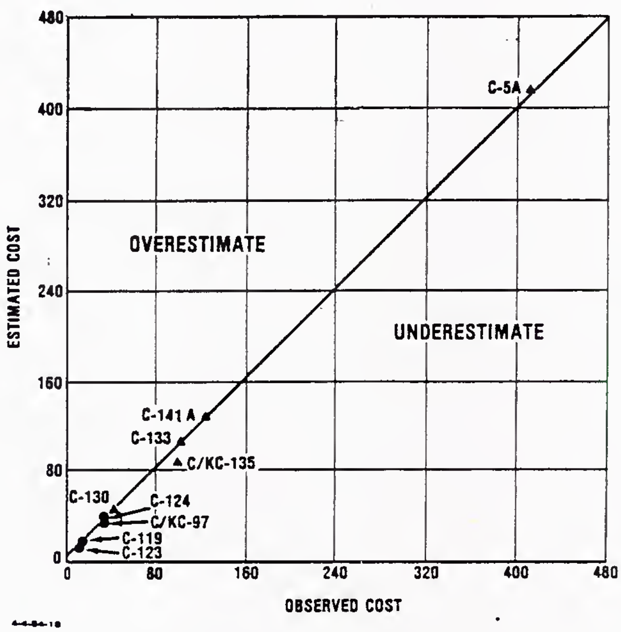

Figure 6. ESTIMATED VERSUS OBSERVED FIRST UNIT FLYAWAY COST OF U.S. CARGO AIRCRAFT (In Millions of FY 1986 Dollars)

not be obtained. Accordingly, a median ratio (6.5) of RDT&E to first unit flyaway cost for the turbine-powered aircraft was developed and used to derive the RDT&E costs in Table 7 for the piston-powered aircraft. The RDT&E CERs are:

Piston-Powered:

$$RC = 2.56(WT)^{0.971}$$

Turbine-Powered:

$$RC = 1.07(WT)^{1.355}$$

where

RC = RDT&E cost in billions of FY 1986 dollars

WT = Empty weight in thousands of pounds

The RDT&E cost estimates based on these equations agree reasonably well with the observed values (See Figures 7 and 8). Figure 9 shows the relationship of the estimated to observed RDT&E costs for both piston-powered and turbine-powered cargo aircraft.

3. Air-to-Surface Missiles

RDT&E and first unit costs for the Hounddog, SRAM, and ALCM were derived from FYDP and Selected Acquisition Report (SAR) data. They were then applied by analogy to Soviet systems.

4. ICBMs and SLBMs

Generally accepted flyaway and RDT&E CERs do not exist for ballistic missiles to the extent that they do for aircraft. The CERs developed in this appendix were derived from two sources. The first, the Five Year Defense Program, was used for the development of the flyaway and RDT&E CERs for the solid propellant ballistic missiles, while the second, aggregated engineering equations, was used for a liquid propellant missile

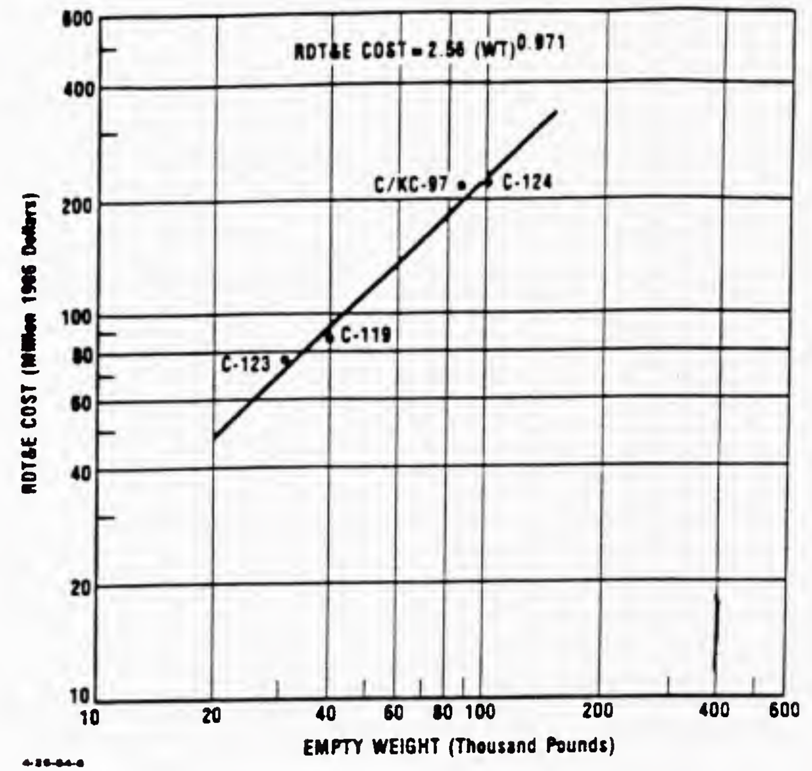

Figure 7. PISTON-POWERED CARGO AIRCRAFT RDT&E COST
(In Millions of FY 1986 Dollars)

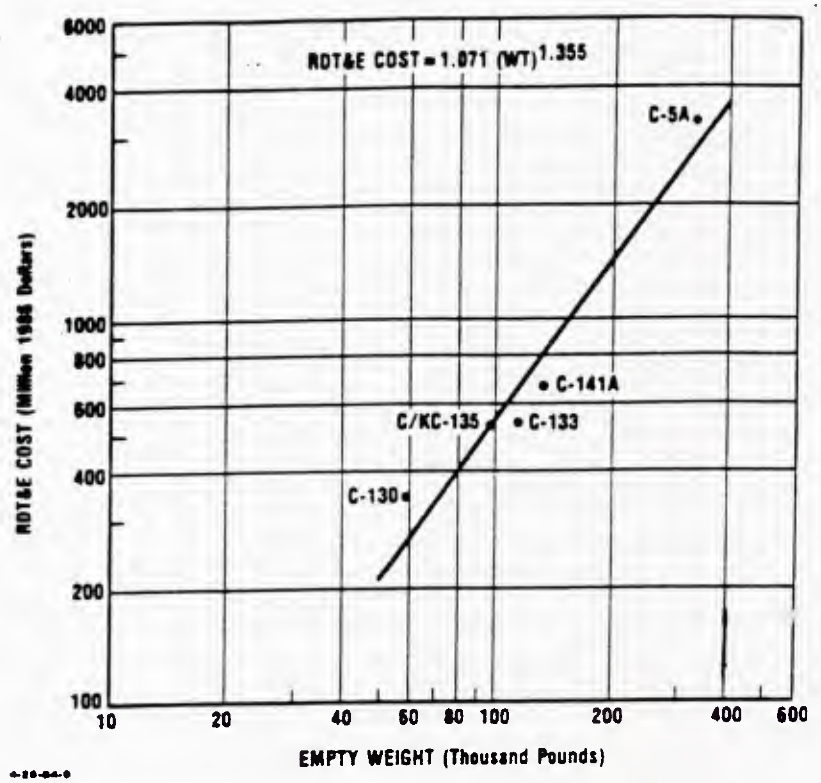

Figure 8. TURBINE-POWERED CARGO AIRCRAFT RDT&E COST
(In Millions of FY 1986 Dollars)

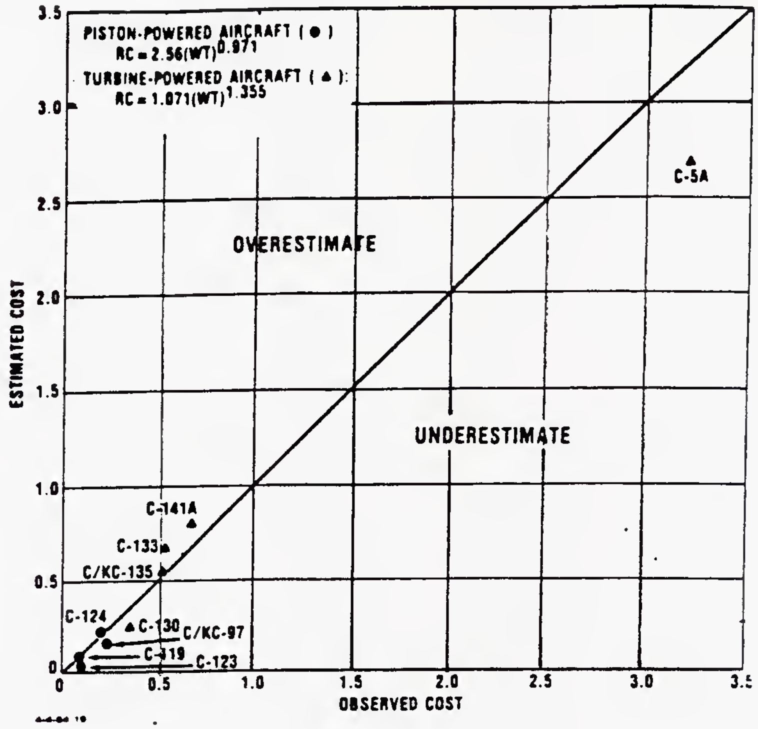

Figure 9. ESTIMATED VERSUS OBSERVED RDT&E COST OF U.S. CARGO AIRCRAFT (In Billions of FY 1986 Dollars)

procurement CER. As will be explained, both the solid fuel CERs were applied to USSR liquid propellant SLBMs and the solid fuel RDT&E CER was applied to USSR liquid propellant ICBMs. Only the USSR liquid propellant ICBM procurement costs were estimated using the second data sources.

Table 8 presents the data that were used to develop the fly-away first unit cost and the RDT&E CERs for the solid propellant missiles. The sources for this information, which was normalized and aggregated into the format of the table, were the present and historical Five Year Defense Program, the present and past FYDP Procurement Annex, and the SAR if a report was available for a particular system. The CERs for the solid propellant missiles are:

Table 8. DATA FOR DERIVATION OF RDT&E AND FLYAWAY COST CERS FOR SOLID PROPELLANT ICBMS AND SLBMs

Missile	Initial Operational Capability	Gross Weight (000 lbs)	RDT&E (Bil. of FY 86 $)	First Unit (Mil. of FY 86 $)
MINUTEMAN II	1966	73.25	4.8	35.7
MINUTEMAN III	1970	77.46	6.9	33.1
M-X	1987	192.00	17.4	102.2
A-3	1964	35.71	6.8	---
C-3	1971	65.00	5.8	35.2
C-4	1980	73.00	7.8	38.9
D-5	1989	130.00	11.3	64.1

Flyaway

$$C = 0.42W^{0.92}(1.0062)^{IOC-1900} \times 1.05$$

where C = the cost of the first unit in millions of FY 1986 dollars

W = gross weight in thousands of pounds

IOC = year of initial operational capability.

RDT&E

$$C = 0.39W^{0.175}(1.0298)^{IOC-1900} \times 1.04$$

where C = the total RDT&E cost in billions of FY 1986 dollars

W = gross weight in thousands of pounds

IOC = year of initial operational capability.

Figures 10 and 11 illustrate the degree of fit between the estimated costs from the use of the CERs and the observed costs from the basic sources for the flyaway first unit cost and the total RDT&E cost of the solid propellant missiles, respectively. Unfortunately, using this CER, the estimated RDT&E costs for the M-X and D-5 missiles are nearly equal. This result is due largely to the small exponent (0.175) which allows for only a small contribution for the added M-X weight. That small

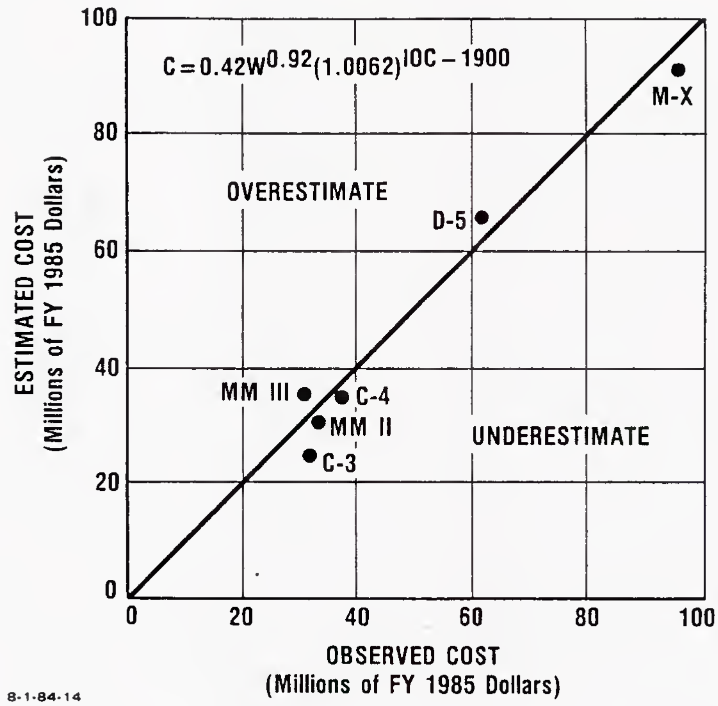

Figure 10. ESTIMATED VERSUS OBSERVED FIRST UNIT FLYAWAY COST OF U.S. SOLID PROPELLANT ICBMs AND SLBMs (In Millions of FY 1985 Dollars)

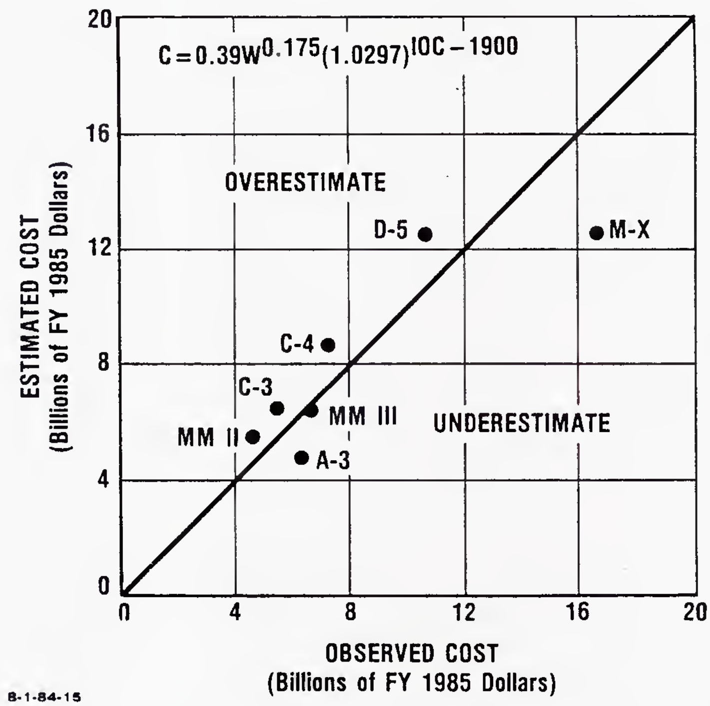

Figure 11. ESTIMATED VERSUS OBSERVED RDT&E COST OF U.S. SOLID PROPELLANT ICBMs AND SLBMs (In Billions of FY 1985 Dollars)

contribution of the greater weight of the M-X is compensated for by the later date of IOC of the D-5 in the CER. This suggests the need to develop a new CER with a larger coefficient for the weight exponent.

The CERs do not include either the number of warheads, the basing mode, hardening or accuracy. It seems likely that the 1.0298 exponent for the IOC variable in the R&D CER, reflecting an increase of 3 percent per year, is a proxy for the complexity of increasing numbers of warheads, hardening and increased accuracy.

Basic data for developing CERs for the two liquid propellant missiles, Atlas and Titan, were not as readily available as were the data for the solid propellant missiles. Therefore, more detailed CERs derived by the Air Force were used as the basis for development of CERs for estimating the cost of the liquid propellant missiles. After an iterative process of testing, all coefficients of the Air Force equations were adjusted so that the computed results were more consistent with the available historical costs. Table 9 presents the adjusted equations for estimating the first unit costs of the U.S. liquid propellant missiles.

One limitation in using the modified Air Force equations to estimate relative U.S./USSR ballistic missile costs is that estimates of missile subsystem weights must be available. For U.S. systems, these data are usually available. For USSR systems, however, generally only estimates of total missile weights were readily available. For this reason, the equations in the table could not be used directly for estimating the costs of USSR systems and a more simplified CER was necessary. Using the U.S. missile CERs, a total missile flyaway first unit cost was developed for both of the U.S. missiles. First unit cost was plotted against gross weight, and this relationship was used to

Table 9. CERS FOR LIQUID PROPELLANT ICBMS
(In Millions of FY 1984 Dollars)

Cost Element[a]	Unit Procurement Cost[b]
Propulsion Stages	$1.8 + (.00007)\ (W1)$
Post Boost Propulsion System	$(.33)\ (.33)\ (W2)^{.485}$
Guidance and Control System	$(1.24)\ (Range/CEP)^{.236}$
Reentry Vehicle[c]	$(.04)\ (H)\ (W3)^{.627}$
Deployment Module	$(.32)\ (W4)^{.379}$
Interstages	$(.03)\ (W5)^{.6}$
Installation and Checkout	$(.07)\ (W6)^{.14}$
General Support	$(.52)\ (C)$

[a]The first six lines are hardware estimating equations. Variables are as follows:

W1 - Weight of propulsion stages (lbs)

W2 - Weight of post boost propulsion system (lbs.)

Range and CEP in nautical miles.

W3 - Weight of reentry vehicle (lbs)

W4 - Weight of deployment module (lbs)

W5 - Total weight of inter- of interstages.

W6 - Missile gross weight (lbs in Thousands)

C - Sum of the first six procurement hardware cost items.

[b]All units costs are for first production unit except for last line which is merely a percentage of hardware costs. SAMSO used learning curve slopes from 85 percent to 95 percent for the various subsystems. For this study, a slope of 90 percent was used for all systems.

[c]Costs are per RV. H is an RV hardness factor.

estimate the flyaway costs of both U.S. and USSR liquid propellant missiles.

Table 10 presents the data used to develop the missile flyaway first unit cost and the resultant first unit CER. This CER was applied only to Soviet ICBMs, since the Soviet liquid fuel SLBMs are small and would be far outside the range of observation of these two U.S. liquid fuel missiles. The solid fuel CER was therefore used for all SLBMs both liquid and solid. As for the Soviet ICBMs, these have almost all been liquid fuel and have been developed over a period of almost 30 years. The time factor (3 percent per year for solid fuel missiles) appeared an important determinant of R&D costs,or at least a proxy for increasing capabilities in multiple warheads, hardening and accuracy -- factors which are in the orginal Air Force equations but are left out of the IDA estimates.

Table 10. DATA FOR DERIVATION OF RDT&E AND FLYAWAY COST CERs FOR LIQUID PROPELLANT ICBMs (In Millions of FY 1986 Dollars)

Missile	Initial Operational Capability (IOC)	Gross Weight (000 lbs)	RDT&E	First Unit
ATLAS	1962	268.7	3,665	39.6
TITAN I&II	1963	334.8	4,018	48.6

<u>Procurement Flyaway CER</u>

$$C = 2.89 + 0.130W$$

where C = the cost of the first unit in millions of FY 1986 dollars

W = gross weight in thousands of pounds.

However, since there are only two U.S. liquid fuel missiles and since they appeared within a year of each other, no such factor could be derived. The solid fuel RDT&E CER was therefore applied to the USSR liquid fuel ICBMs.

5. Fleet Ballistic Missile Submarines (SSBNs)

The CER for procurement of SSBNs was developed in IDA Paper P-1732, Cost Estimating Relationships for U.S. Navy Ships. The linear CER translated into FY 1986 dollars is:

$$\text{Cost} = 33 + 99.1D \times 1.05$$

Where Cost is in FY 1986 dollars

D is the submerged displacement in thousands of long tons.

This relationship is shown in Figure 12. In Figure 13 the degree of fit between the estimated and observed costs of the SSBN submarines can be observed.

The FBM support ships are in this category in addition to the SSBNs. Such vessels generally resemble underway replenishment ships. The CER for this category of ship is used, specifically:

$$\text{Cost} = 41.6 + 6.15D \times 1.05$$

Where Cost is the estimated cost of an underway replenishment ship in millions of FY 1986 dollars

At present there are no CERs for the estimation of RDT&E costs of SSBNs. RDT&E costs over time for the FBM system and the Trident system are available in the historical and current FYDPs. These costs were converted to constant year 1986 dollars and accumulated for both the FBM system and the Trident systems. The estimated RDT&E costs for the ballistic missiles were subtracted from these FYDP costs and the residual was assumed to be the RDT&E costs for the SSBNs.

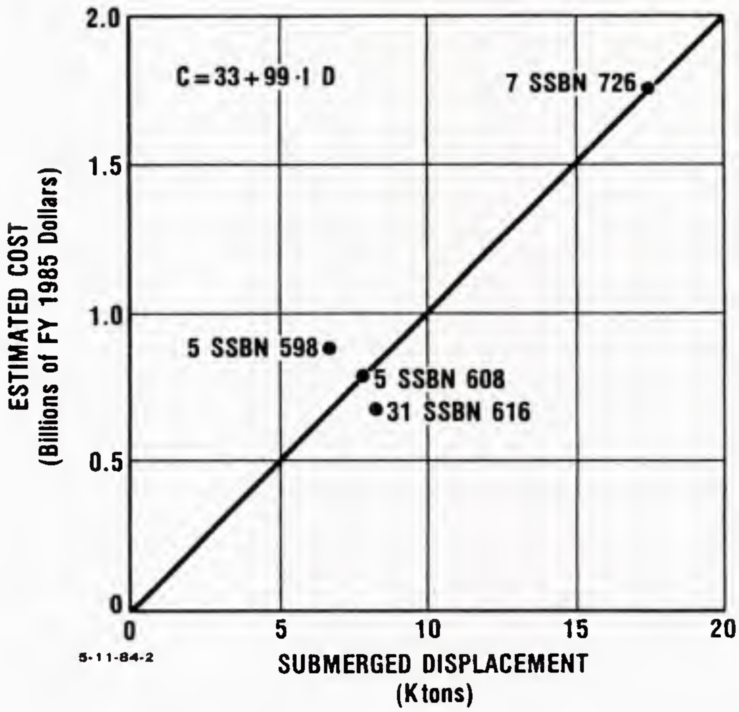

Figure 12. ESTIMATED COST VERSUS SUBMERGED DISPLACEMENT FOR FLEET BALLISTIC MISSILE SUBMARINES (SSBN)

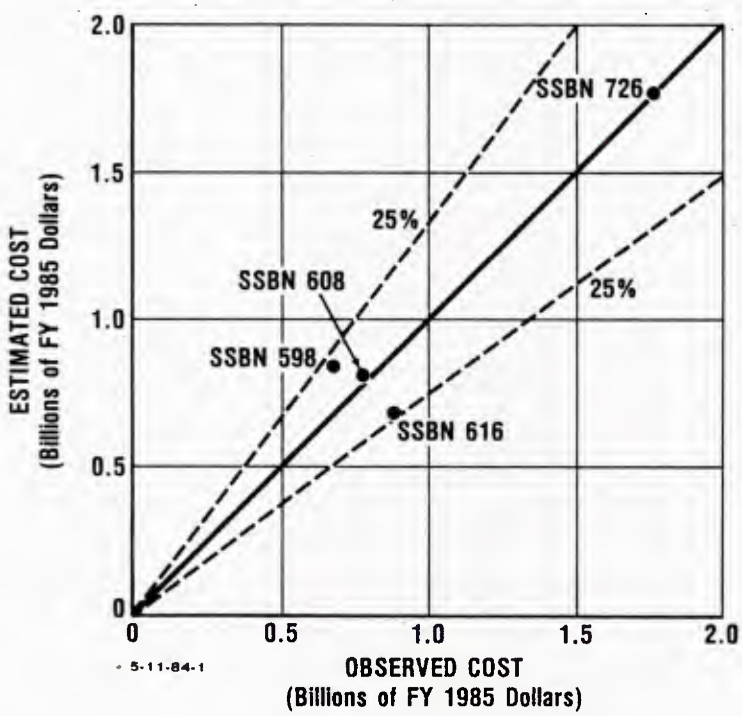

Figure 13. ESTIMATED VERSUS OBSERVED COST OF FLEET BALLISTIC MISSILE SUBMARINES

6. RDT&E Cost Factors

Many of the developed systems were not completely new systems. Rather they were modifications. Based on judgments for the R&D community, the systems were divided into new systems, major modifications and moderate modifications. Major modifications were assumed to be as expensive as three-quarters of a full program, while moderate modifications were assumed to be half as expensive as a new program. The factors used are shown in Tables 11 and 12.

D. OTHER APPROPRIATION CATEGORY COST FACTORS

In the previous sections of this report the development of CERs for the estimation of the initial or flyaway costs for major equipment and the RDT&E costs were discussed. This section addresses the derivation of the factors used to estimate the other weapon system costs, namely associated costs other than flyaway.

The primary data source for all of these factors was the historical FYDP. The total program costs (TOA) by appropriation by year for the program elements comprising the Strategic Offensive Forces were extracted from the historical and current FYDP. These program elements were adjusted through additions and deletions as defined by the Strategic Offensive DPPC. The TOA then year dollars were inflated or deflated, as appropriate, to constant year 1986 TOA dollars to derive the factors. The TOA was then converted to constant year 1986 outlay dollars in the program. This process resulted in the use of 26 years of normalized cost data (FY 1986 outlays) by appropriation for each program element/weapon system in the U.S. strategic offensive force. Those normalized cost data by system over time were then associated to some aspects of the weapon system (incremental,

Table 11. COST FACTORS FOR RDT&E (U.S. FORCES)

Category	U.S. Weapon System	Factor
Bombers	B-47	1.00
	B-52 A-F	1.00
	B-52 G/H	0.75
	B-58	1.00
	B-1A	Fixed
	Amt.	
	B-1B	1.00
Tankers	KC-97	1.00
	KC-135	1.00
	KC-135 Reengine	Fixed Amt.
	KC-135 AFR/ANG	0
Air-to-Surface Missiles	HOUNDDOG	1.00
	SRAM	1.00
	ALCM	1.00
ICBMs	Atlas	1.00
	Titan I & II	1.00
	Minuteman I	0.75
	Minuteman II	0.75
	Minuteman III	0.50
	M-X Peacekeeper	1.00
SLBMS	Polaris A-1	1.00
	Polaris A-2	0.75
	Polaris A-3	0.75
	Poseidon C-3	1.00
	Poseidon/Trident C-4	1.00
	Trident D-5	1.00
Submarines	SSBN 598	1.00
	SSBN 608	1.00
	SSBN 616	1.00
	SSBN 627	1.00
	SSBN 640	1.00
	SSBN Conversion	1.00
	Trident System	1.00
	Trident SSBN	1.00

Table 12. COST FACTORS FOR RDT&E (USSR FORCES)

Category	USSR Weapon System	Factor
Bombers	BEAR B/C	1.00
	BEAR G	0.75
	BEAR H ALCM	0.75
	BISON	1.00
	BLACKJACK	1.00
	BLACKJACK ALCM	0.50
Tankers	BISON TANKER	1.00
	NEW TANKER	1.00
Air-to-Surface Missile	AS-3	1.00
	AS-4	1.00
	AS-15	1.00
ICBMs	SS-6	1.00
	SS-7	1.00
	SS-8	1.00
	SS-9 Mod 1	1.00
	SS-9 Mod 2	0.50
	SS-9 Mod 3	0.75
	SS-9 Mod 4	0.50
	SS-X-10	1.00
	SS-11 Mod 1	1.00
	SS-11 Mod 2/3	0.50
	SS-13 Mod 1	1.00
	SS-13 Mod 2	0.50
	SS-16 Not Depl.	1.00
	SS-17 Mod 1	1.00
	SS-17 Mod 2	0.50
	SS-17 Mod 3	0.50
	SS-18 Mod 1/3	1.00
	SS-18 Mod 2	0.50
	SS-18 Mod 4	0.75
	SS-18 FO Mod A	1.00
	SS-19 Mod 1	1.00
	SS-19 Mod 3	0.50
	SS-19 Mod 2	0.50
	SS-X-25	1.00
	SS-X-24	1.00

(Continued)

Table 12. (concluded)

Category	USSR Weapon System	Factor
SLBMs	SS-N-4	1.00
	SS-N-5	1.00
	SS-N-6 Mod 1	1.00
	SS-N-6 Mod 2/3	0.50
	SS-N-8	1.00
	SS-N-17	1.00
	SS-N-18 Mod 1	1.00
	SS-N-18 Mod 2	0.50
	SS-N-18 Mod 3	0.50
	SS-NX-23	1.00
	SS-NX-23 FO	1.00
	SS-NX-20	1.00
	SS-NX-20 FO	1.00
Submarines	GOLF	1.00
	HOTEL	1.00
	YANKEE	1.00
	DELTA	1.00
	TYPHOON	1.00

yearly average, or total force levels) or to some characteristic of the major equipment (weight, thrust, etc.).

Such factors are derived on an aggregated basis and from only a few data points. But due to the specific and limited application of the results, relative comparisons may be made to provide useful long term trend analyses on a broad, general basis.

1. Other Cost Factors for Bomber Forces

Military Construction was estimated to be $1.2 million per incremental pre-1980 bomber, $1.9 million per incremental post-1980 bomber, $0.06 million per incremental tanker, and $0.26 million per incremental bomber being modified as a missile carrier.

Aircraft procurement--initial support was estimated to be 20 percent of the procurement cost of new aircraft.

Aircraft procurement--recurring was estimated to be $0.021 million per bomber maximum thrust (in thousands) times the average number of aircraft per year. For tenant tankers, use $0.006 million per tanker maximum thrust (in thousands).

Operations and maintenance was estimated to be $0.014 million per bomber DCPR weight (in thousands) times the average number of bombers per year. For tenant tankers, use $0.007 million per tanker DCPR weight (in thousands).

Military personnel was estimated to be $0.017 million per bomber or tanker maximum thrust (in thousands) times the average number of bombers or tankers per year.

The three USSR air-to-surface missiles (ASMs) were estimated using the identical factors as the three U.S. ASMs, as shown in Table 13.

Table 13. AIR-TO-SURFACE MISSILE OPERATING COST FACTORS (In Millions of FY 1985 Dollars)[a]

	HOUNDDOG/AS-3	SRAM/AS-4	ALCM/ALCM
Military Construction (Per ASM Force)	0	40.	217.
Procurement Support (Percent of Flyaway)	(0)[b]	(25)	(25)
Procurement Recurring[c]	0	0.016	0.016
Operations & Maintenance[c]	0.011	0.007	0.011
Military Personnel[c]	0.044	0.022	0.013

[a] The calculated 1985 dollar costs were converted to 1986 dollars by a factor of 1.05.

[b] Included in the cost of the missile.

[c] Cost per average number of missiles per year.

2. Other Cost Factors for ICBM Forces

Military construction for the U.S. systems was derived from FYDP totals. Generalized factors for the USSR systems were developed from the U.S. totals on a per incremental unit basis. They are as follows:

Category	Military Construction Cost Per Incremental Unit (Millions of FY 1985 Dollars)[a]
Pre-1980 Systems	
Liquid Missile Systems	10.0
Solid Missile Systems	4.0
Post-1980 Systems	
Liquid Missile Systems	20.0
Solid Missile Systems	30.0
All Systems Modifications	0.1

[a] The calculated dollar costs were converted to 1986 dollars by a factor of 1.05.

Missile procurement--initial support was estimated to be 50 percent of the procurement cost of new missile.

Remaining CERs for ICBM forces are:

Category	Cost Per Average Number of Missiles Per Year (Millions of FY 1985 Dollars)[a]		
	Procurement-Recurring	Operations & Maintenance	Military Personnel
Pre-1980 Systems			
Liquid Missile Systems	0.210	0.310	1.750
Solid Missile Systems	0.210	0.075	0.275
Post-1980 Systems			
Liquid Missile Systems	1.050	2.000	2.500
Solid Missile Systems	1.050	1.575	0.440

[a] The calculated 1985 dollar costs were converted to 1986 dollars by a factor of 1.05.

The costs of the USSR SS-X-25 (MOBILE) system were assumed to be more expensive because of its mobility. An additional 10 percent was included for military construction, a 100 percent factor was included for procurement support instead of the 50 percent used for other missiles, and all recurring cost factors were increased by 50 percent.

3. Other Cost Factors for SLBM Forces

For the SLBMs no additional cost factors were estimated beyond those for RDT&E and major equipment procurement. Operating and support costs were assumed to be included in the SSBN factors.

Military construction total costs from the FYDP were inputted for the U.S. FBM system and the Trident system. For the USSR systems, the Yankee and Delta class boats were assumed to be similar to the Polaris/Poseidon; therefore, one-half of the FBM system military construction costs was allocated to each of the Yankee and Delta systems. In the same manner, the military construction costs of the Trident system were inputted for the Typhoon system.

A factor was not derived for SSBN procurement support. It was assumed to be included in the cost of the boat.

The procurement recurring, operations and maintenance, and military personnel factors were derived from the U.S. FBM system and yielded factors of $1,140, $2,803, and $768 per submerged displacement long tons per boat per year. Costs were then estimated by using the respective factors for the three cost elements for all of the SSBNs, except for the U.S. Trident and the USSR Typhoon. The average cost per boat per year of the three cost elements for the Trident system did not fit a similar pattern; therefore, the costs per boat per year for the Trident system were also used for the Typhoon system.

In a similar manner, factors per ship per year for the above three cost elements were derived from the FBM support ships program element, and then used to estimate the cost of the U.S. and USSR support ships.

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